Collaboration with Williams International to Demonstrate the Characteristics of a Foam-Metal-Liner Installed Over-the-Rotor of a Turbofan Engine

A Williams International FJ44-3A 3000-lb thrust class turbofan engine was used as a demonstrator for foam-metal liner installed in close proximity to the fan. Two foam metal liner designs were tested and compared to the hardwall. Traditional Single-Degree-of-Freedom liner designs were also evaluated to provide a comparison. Normalized information on farfield acoustics is presented in this paper. The results show that up to 5 dB PWL overall attenuation was achieved in the forward quadrant. In general, the foam-metal liners performed better when the fan tip speed was below sonic.
Collaboration with Williams International to Demonstrate the Characteristics of a Foam-Metal-Liner Installed Over-the-Rotor of a Turbofan Engine.

Acoustics Technical Working Group Meeting
23-24 September-2008

Dan Sutliff (GRC)  Dave Elliott (GRC)  Mike Jones (LaRC)
Tom Hartley (Williams International)
Outline

Background
FJ44 / Liner
AAPL Facility / Test
Results
Discussion
Rationale

Improve upon Traditional Liners Used in Turbofan Engines by Replacing with Foam Metal Liner

• Traditional Liners are “tuned” - Single Degree of Freedom. (i.e. limited Band Width)

• Limited BW and/or unique design required.

• Not suitable for adverse environments (i.e. close to /over the rotor) ‘distant’ from source.

• “Over the rotor” application requires rub & containment consideration.

• Ideally - would like to use a single component for improved attenuation, fan rub & containment.
Historical Outline

• 2003 - 2004 RTX / LaRC preliminary studies of foam metal material and acoustic characteristics
• 2005 - 2006 ANCF tests of Foam Metal Liner in lab
• April-2007: WI representatives attended Acoustics Technical Working Group meeting and expressed interest in applying foam metal liner to FJ44 engine.
• 23-May-2007: RTA/AAPL team visited WI and outlined collaboration with each parties supplying area of expertise; with less than $0-50K changing hands ($0)
  – WI:
    to provide engine & support (ideally: turnkey!!)
    liner fabrication
    engine integration
  – NASA:
    provide manpower and expertise for testing
    expertise and data systems for acoustic testing
    material property investigation
    liner design guidance
• IPP seed fund awarded July 2007
• Delineated though Simplified Space Act agreement signed October 2007
• Added Hawker Beechcraft Corporation and Dr. W. Eversman to collaboration effort on April 2008
Metallic Foams

60 ppi, 6% Density

Advantages:

• Excellent acoustic absorption characteristics
• Ductile alloy with high temperature capability
• Sheet product identified as unusually high impact resistance
• Processing technology developed with Porvair (including face sheet brazing and complex shapes)

Flammability test: foam unaffected by 1000°C/30 min in a burner rig. Long life in oxidizing environment to at least 800°C.

Immersion tests: foam specimens with a variety of size and shapes in various fluids such as water, skydroll, advanced hydraulic fluid and jet fuel (2 hr immersion + 2 hr ambient drying). Does not readily absorb fluids.

Stress Tests: Mechanical properties surveyed, including compression, bending, tensile (w/face sheets). Can withstand expected mechanical loads.

Rub Tests: Completed
Impedance Tube Tests

Normal Impedance Tube Tests at LaRC

- Porosities (20 - 100 ppi)
- Densities (4-8%)
- (2” x 2” x 0.425”) samples
- Two-microphone procedure
- Two-thickness procedure

![Diagram of acoustic drivers, reference microphone, and test liner.]

![Graph showing normalized impedance and absorption coefficient versus frequency.
- Measured resistance and reactance.
- Predicted resistance and reactance.
- Three thicknesses: 1”, 2”, and 3”.

Abs. Coeff.

Frequency, Hz
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**Fan Case & Insert Design**

**Current HW1**

**Flow**

**Rotor path**

314 Stainless Steel:
- A1/A1t - 80 ppi / ~8%
- A2 - 40 ppi / ~8%

**FML (HW2)**

**THIS AREA TO HAVE 20% OPEN AREA WITH Ø.030” HOLES (1:1,L:D,WALL:HOLES)**
FML Close-up
Outline

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Placement in AAPL
Schedule as Tested

CONFIGURATIONS TESTED:

- HW0  Hardwall configuration - original fan shroud (phased array)
- HW1  Hardwall configuration - New inlet & baseline fan shroud
- HW2  Hardwall configuration
- A1-80 Fan case only treated - 80 ppi foam
- A1t-80 Fan case only treated - 80 ppi foam near the rotor only
- A2-40 Fan case only treated - 40 ppi foam
- SDOF-71 Inlet only treated - C-71 - Hybrid thick/thin treatment zones
- SDOF-72 Inlet only treated - C-72 - Thin core treatment (new/orig fan shroud)

DATA TAKEN:

- Nearfield Acoustic 15-mic array @ 10’/10’
- Farfield Acoustic 28-mic array @ ~60’ (not planar)
- In-Duct Dynamic 9-high response transducer linear array in inlet
- Rotating Rake Modal 14-mic radial distribution in inlet
- Flow Data Inlet: Pt rakes; Ps wall taps
  Bypass: Pt/Tt rake
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Near-Field Data Reduction

- Data acquired synchronously sampled to fan shaft @ 144/rev
- Frequency/time domain averaged
- Spectra for each microphone integrated over ‘harmonic bands’
  i.e. $\frac{1}{2}$ to $1\frac{1}{2}$ harmonics
  or 8 to 24 shaft orders (etc)
  multiplied by area, etc, to obtain PWL
- Overall/Broadband/Tones
Nearfield Directivity Plots

1st Harmonic Band / BPF

(5 dB / division)  

(Identical scales on plots)

Overall  

Broadband  

Tonal

PWL-dB

Mic Angle from Axis (deg)

70% N1-corr

94% N1-corr
Nearfield Results (10’ inlet arc)

**Graphs:**
- **2x BPF**
- **2nd Harm Band**
- **2xBPF**
- **SONIC ROTOR tip speed**
- **OVERALL**
- **BROADBAND**
- **TONAL**

**Legend:**
- A2 (40 ppi)
- A1 (80 ppi)
- A1t

**Axes:**
- Shaft Order (freq / (rpm/60))
- N1-corr
- Sonic rotor tip speed

**Data:**
- 55% 60% 65% 70% 75% 80% 85% 90% 95% 100%
- 0 8 16 24 32 40 48 56
- 0 2 4 6 8
- -2 -4

**Notes:**
- Sonic rotor tip speed
- Overall broadband trends
- Tonal data comparison
Acoustic Summary (1)

9” SDOF liner in inlet:
- SDOF1 - thick liner (except TT1 cut-out)
  - Fan BPF targeted at 100% N1c
- SDOF1 - thin liner
  - Fan BPF targeted at 75% N1c

Graphs showing variation in sonic rotor tip speed and N1-corr.
**Performance (1)**

**Limited instrumentation:**
- 4 Pt (5 ports) rakes in inlet w/ Ps at base
- 3 Pt / 3Tt rakes in bypass (behind stators)

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<th>Pt/Tt-rakes</th>
<th>Inlet</th>
<th>Bypass</th>
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<tr>
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<tr>
<td>R5</td>
<td>9.769</td>
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<tr>
<td>Riw</td>
<td>0.875</td>
<td>7.000</td>
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**Simple flow computations:**

\[
\dot{m} = \pi \sqrt{\frac{2}{R} \left( \frac{C_o^2 - \bar{C}_s^2}{R} \right)} \left( \frac{P_t}{P_s} \right)^{\frac{\gamma - 1}{\gamma}} \left( P_t - P_s \right)
\]

\[
\eta_{adiabatic} = \left( P_{t\text{ratio}}^{\frac{\gamma}{\gamma - 1}} \right) / (T_{t\text{ratio}} - 1)
\]

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<th>50%</th>
<th>55%</th>
<th>60%</th>
<th>65%</th>
<th>70%</th>
<th>75%</th>
<th>80%</th>
<th>85%</th>
<th>90%</th>
<th>95%</th>
<th>100%</th>
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WI used acquired test parameters as input to engine simulation deck to estimate performance impact of the FML on select engine performance parameters.

(#’s relative to HW2 - effect of FML)

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<th>Δ Fn</th>
<th>100% N1c</th>
<th>88% N1c</th>
<th>70% N1c</th>
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<td>+0.7%</td>
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<table>
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<th>88% Fn</th>
<th>70% Fn(?)</th>
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<td>A1</td>
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Foam Metal Liner was used successfully in an high-speed turbofan engine:
   • Significant attenuation achieved from 2 acoustic designs
   • Performance penalty at optimum acoustic design
   • No performance penalty at off-optimum acoustic design

FML attenuates tones & broadband / not shocks(?).

Aero/Acoustic design was not integrated.